

The University of Chicago

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COPPER ORES OF SOUTHWESTERN OREGON

A PART OF A DISSERTATION SUBMITTED TO
THE FACULTY OF THE DIVISION OF THE
PHYSICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF GEOLOGY AND PALEONTOLOGY

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WAYNE RUSSELL LOWELL

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THE PARAGENESIS OF SOME GOLD AND COPPER ORES OF SOUTHWESTERN OREGON.¹

WAYNE RUSSELL LOWELL.

ABSTRACT.

Copper ores in Southwestern Oregon are associated with greenstones and serpentines, while gold ores are associated with Tertiary lavas and nearly all of the pre-upper Cretaceous rocks. The ores consist of hypogene minerals deposited by mineralizing solutions ascending along fractures, faults and shear zones. The mineralizing solutions are believed to be related to quartz-diorite and related rocks. The ores represent deposition in the hypo-, meso- and epithermal zones. Generally deposition occurred in three stages separated by minor fracturing. Gold and copper minerals were deposited in the intermediate stage. Calcite and hydrous gangue minerals—chlorite, sericite and prehnite—were well developed along fractures in the sulphides during the late stage. Secondarily enriched ores are comparatively rare. Oxidation zones are commonly 25 to 30 feet deep rarely exceeding 100 feet. Unusual minerals identified included cassiterite, native bismuth, and tellurium.

INTRODUCTION.

THE mines included in this investigation are located in the area from Cottage Grove on the north to the Oregon-California boundary on the south between meridians 122° 30' and 124° 00'. Those of the Bohemia district are situated in the Cascade Range about 35 miles by highway southeast of Cottage Grove, Oregon, and the remainder are located in the drainage basins of the South Umpqua, Rogue and Illinois rivers. Grants Pass, Oregon, is near the center of this area which has a radius of about 35 miles.

Ore specimens were collected from 34 mines (Fig. 1), selected on the basis of past production, accessibility of the workings, and present development. In so far as possible the specimens were collected from the veins, but in the case of inaccessible workings specimens were taken from the dumps.

¹ Part of a dissertation submitted to the faculty of the University of Chicago for the degree of Doctor of Philosophy, 1942.

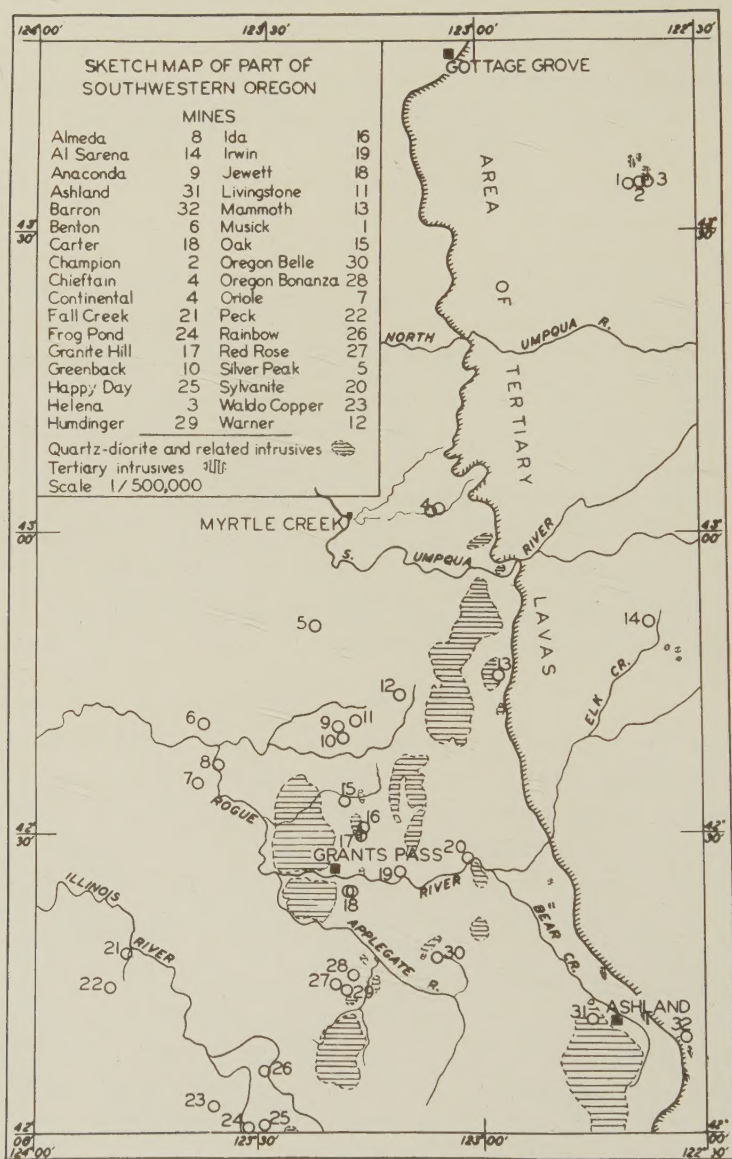


Fig. 1

Due to the widespread mineralization of southwestern Oregon several reports dealing with the geology, mineral resources and mines of this region have been published. The geology of five 30 minute quadrangles has been mapped; these include the Roseburg, Riddle, Butte Falls, Medford, and Grants Pass quadrangles. In addition, U. S. Geol. Surv. Bulletin 893 includes a reconnaissance geological map of the Cascade Range and a more detailed geologic map of the Bohemia district. These maps together with reports dealing with mineral resources and mine descriptions were prepared by the U. S. Geological Survey, by the Oregon State Department of Geology and Mineral Industries, or as co-operative projects by the two organizations.

This investigation was undertaken in the hope that a regional paragenesis study of ores from several mines of the area would yield data pertinent to the temperature and pressure conditions prevailing during the mineralization period and possibly information as to the effect of structural control on the circulation of the mineralizing solutions. The study was outlined, developed and completed under the direction of Dr. Edson S. Bastin. Dr. Norman L. Bowen gave frequent aid and advice in the petrographic work. The Oregon State Department of Geology and Mineral Industries contributed to the study by financing part of the field expenses and by furnishing unpublished data about the mines.

GEOLOGY.

Stratigraphy.

Paleozoic or Older Rocks. These rocks include the older schists and metavolcanics and metasediments, described by F. G. Wells,² for the Grants Pass and Medford quadrangles. The older schists occupy 40 or 50 square miles along the southern border of the area and lie partly in the southeastern corner of the Grants Pass and partly in the southwestern corner of the Medford quadrangles. Because of severe metamorphism they

² Wells, F. G.: Preliminary geologic map of the Grants Pass Quadrangle, Oregon. Oregon Dept. Geol. and Min. Indus., 1940. Preliminary geologic map of the Medford Quadrangle, Oregon. Oregon Dept. Geol. and Min. Indus., 1939.

are considered the oldest rocks of the region. The metavolcanics, enclosing lens-shaped beds of metasediments, make up a thick series of rocks which underlie a considerable part of the Grants Pass, Riddle and Medford quadrangles. The metavolcanics are pale green to greenish-gray with textures varying from fine to moderately coarse-grained. Much of the series consists of porphyritic rocks with plagioclase and former pyroxene phenocrysts in a microcrystalline matrix. The metasedimentary rocks include beds of argillite, chert, quartzite and limestone. The general strike is usually east of north with steep southeast dips. This Paleozoic series of rocks is apparently the southern extension of the greenstones and May Creek schist as mapped in the Riddle³ and Butte Falls quadrangles.⁴

Jurassic Rocks. The Galice formation (L. Jurassic) outcrops mainly in the Riddle Quadrangle where it includes fine-grained, dark slate with some sandstone and conglomerate, and is mapped separately from the parallel bands of greenstone. Apparently equivalent rocks⁵ in the Grants Pass Quadrangle are interbedded with and overlain by volcanic rocks that are nearly the same age as the sedimentaries and are considered to be Jurassic in age. The Dothan formation (U. Jurassic) occurs mainly in the Riddle Quadrangle; it consists chiefly of hard sandstone with some conglomerate and some gray shale. The Jurassic rocks have a general N. 30° E. strike and dip steeply to the southeast.

Cretaceous Rocks. The Cretaceous rocks of the mapped area are confined to the northern part of the Riddle and the southern part of the Roseburg quadrangles but probably extend into the unmapped area to the west. In the mapped area the Cretaceous rocks include the Myrtle, Chico, Horsetown and Knoxville formations consisting of shales, sandstones and conglomerates. The Chico formation also outcrops as a narrow band along the southwest side of Bear Creek Valley in the Medford Quadrangle where

³ Diller, J. S., and Kay, G. F.: Geologic atlas of the United States, Riddle Folio, No. 218, Oregon. U. S. Geol. Surv., 1924.

⁴ Wilkinson, W. D.: Reconnaissance geologic map of the Butte Falls Quadrangle, Oregon. Oregon Dept. Geol. and Min. Indus., 1941.

⁵ Wells, F. G.: op. cit. (Grants Pass Quadrangle).

it unconformably overlies the older rocks and has a general northwest strike with dips varying up to 30° N.E.

Tertiary Rocks. The Umpqua formation (Eocene) outcrops as a northwest trending band on the northeast side of Bear Creek Valley in the Medford Quadrangle where it generally strikes northwest and dips northeast at a low angle beneath the Tertiary volcanics to the east. Farther north in the Butte Falls Quadrangle the strike is more eastwest with low southerly dips. In the Roseburg Quadrangle the Umpqua formation covers about one-third of the area. Here the average strike is northeast, although there is much variation and dips are both northwest and southeast.

Tertiary lava flows occupy approximately the eastern third of the region and extend from Cottage Grove on the north to Ashland on the south (Fig. 1). These flows belong to the western Cascade volcanic rocks and have been divided into two groups⁶ on the basis of types of flows. One group consists of black lavas and volcanic breccias with minor rhyolite, andesite and tuff; the second group is dominantly andesitic lavas and volcanic breccias. The lavas, ranging in age from Eocene to middle Miocene, have a gentle east to northeast dip.

Intrusive Rocks. Intrusive rocks ranging in composition from peridotite, gabbro, diorite, quartz-diorite, granodiorite and granite outcrop in the region (Fig. 1). Generally the exposed portions of these rocks are comparatively small; however, a few bodies are many square miles in extent. Usually the more basic rocks have the smallest areal outcrops. The peridotite rocks have been more or less altered to serpentine. The ages of the intrusives vary from Mesozoic (late Jurassic?) to late Miocene. In the Roseburg Quadrangle gabbro intrudes the Myrtle formation (Cretaceous) and diabase cuts the Umpqua formation (Eocene);⁷ in the Grants Pass Quadrangle the youngest intru-

⁶ Callaghan, Eugene, and Buddington, A. F.: Metalliferous mineral deposits of the Cascade Range in Oregon. U. S. Geol. Surv. Bull. 893, Plate I, 1938.

⁷ Diller, J. S.: Geologic atlas of the United States, Roseburg Folio, No. 49, Oregon. U. S. Geol. Surv., 1898.

sives are older than the Chico formation (Cretaceous);⁸ while in the Medford⁹ and Butte Falls¹⁰ quadrangles the diorite sills and basalt dikes cut Tertiary lavas and are late Tertiary in age. Contact metamorphic aureoles have been developed in the intruded rocks.

In the Bohemia district small stocks and dikes of intrusive rocks,¹¹ ranging from granite and dacite porphyry to diorite, cut the Tertiary lavas with the development of contact metamorphic aureoles. The veins and small elongate stocks have a general parallel strike of west to northwest.

Structure.

The structures of the rocks of this region are very complex. Folding and faulting have been operative over a long period and the rocks older than the Chico formation (U. Cretaceous) have been strongly deformed.

The rock formations as mapped in the area are exposed on the surface as bands trending about N. 30° E. The strike of the formations closely follows this trend although locally strikes and dips vary considerably. Generally steep to vertical dips to the southeast prevail.

The oldest rocks of the region outcrop in the southeastern part of the area and the younger metamorphics occur to the northwest. Along the northwest edge of the Grants Pass Quadrangle, Jurassic rocks, striking northeasterly and dipping steeply to the southeast, appear to underlie the older metavolcanics, a relation that may be due either to overturning or overthrusting of the metavolcanics over the Jurassic rocks.

A major synclinal structure is indicated by the northwestward dip of the metavolcanics of the Medford Quadrangle and by the southeastward dip of these rocks in the Grants Pass Quadrangle.

⁸ Wells, F. G.: op. cit. (Grants Pass Quadrangle).

⁹ Wells, F. G.: op. cit. (Medford Quadrangle).

¹⁰ Wilkinson: op. cit.

¹¹ Callaghan and Buddington: op. cit., p. 41.

Faults in the pre-Cretaceous rocks are numerous. Several fairly large faults are shown on the geologic maps of the area. Most of the mine workings reveal one or more faults.

THE ORE DEPOSITS.

Copper Deposits.

Distribution. Copper prospects and mines in the area are not localized. In the past several districts have been prospected and studied, and prospects and mines have been developed in each. Of these districts the Takilma-Waldo and Silver Peak areas are important. The Almeda mine is reported to have been a copper producer and to have considerable copper ore reserves. Some development work has been done in the area south of Drew, Oregon, at the Banfield and Mammoth Lodge claims. One of the earliest areas prospected for copper was the Rancherie and Fall Creek area west of Selma, Oregon, on the Illinois River.

Relation to Country Rock. The copper deposits occur in metamorphic rocks. Various descriptions stress the association of copper with greenstones and with serpentine which is abundant in the region and has been derived by alteration of ultra-basic intrusive rocks of peridotitic and pyroxenitic types. Serpentinized rocks have been intruded into all the pre-Cretaceous rocks and are probably younger than most of the greenstones with which they are in contact.¹² Of the five copper mines and prospects visited, three are associated with greenstones and serpentine, one (Silver Peak mines) with greenstone and schist, and one (Mammoth Lode) with the May Creek schist.

Associated Intrusive Rocks. Intrusive rocks outcrop near two of the mines and are known to occur in the vicinity of two others; serpentinized rocks are closely associated with three of the mines. The Mammoth Lode and Oak mines are near quartz-diorite masses and quartz-diorite rocks are exposed a few miles distant from the Silver Peak mines and the Waldo Copper mine.

Structural Relations. Faulting or shearing has been operative at five copper mines and prospects. Evidence of post-min-

¹² Wells: op. cit. (Grants Pass Quadrangle).

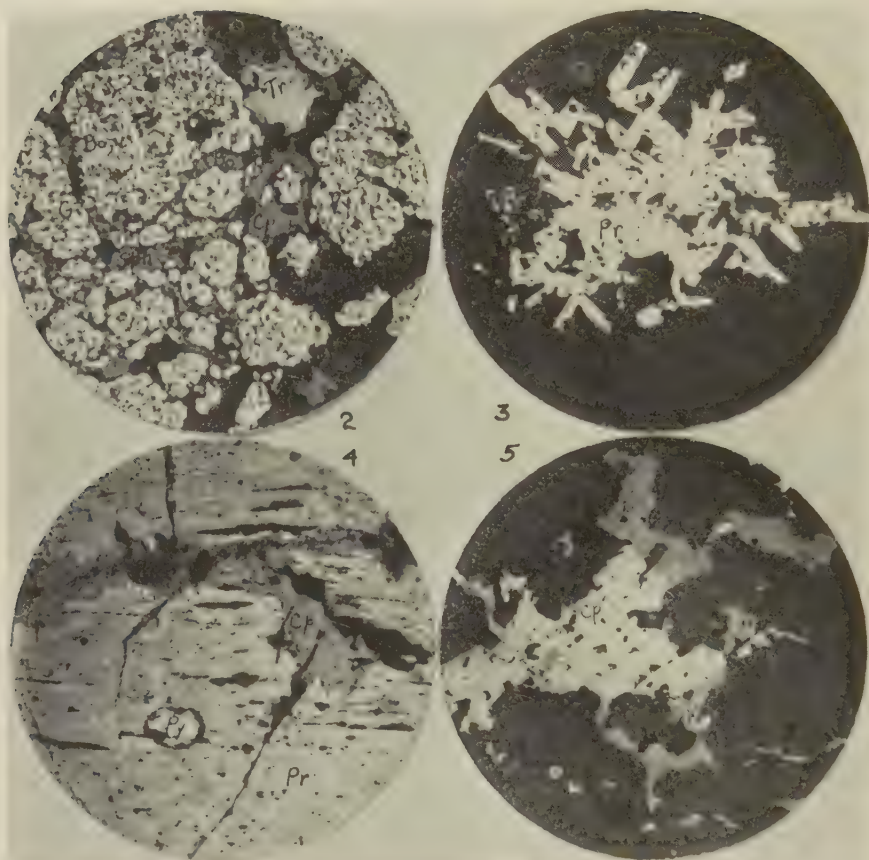


FIG. 2. Sphalerite (Sph)-Bornite (BO)-Galena (G)-Chalcopyrite (Cp) segmented veinlets in pyrite (Py). Tetrahedrite (Tr). Barite (Ba) replaces quartz (Q). (Silver Peak mines.) Magnification 48 X.

FIG. 3. Pyrrhotite (Pr) automorphically replacing quartz (Q). (Waldo Copper mine.) Magnification 48 X.

FIG. 4. Pyrite (Py) replacement of pyrrhotite (Pr) develops rounded grain. Chalcopyrite (Cp) replaces pyrrhotite along a fracture (Fall Creek Copper mine.) Magnification 48 X.

FIG. 5. Bornite (Bo) and chalcopyrite (Cp) reversible relationships. (X) is an area of bornite-chalcopyrite intergrowth similar to exsolution textures obtained by Schwartz in the laboratory. Matrix is quartz. (Silver Peak mines.) Magnification 48 X.

eral movements is abundant, but pre-mineral faulting or shearing is not so obvious, although it can be inferred from polished specimens which show, for nearly all the ores, that fracturing followed deposition of the earliest as well as the later formed minerals, usually with later minerals filling the fractures. The evidence implies a lack of static conditions during and following mineralization, and it seems reasonable to infer that stresses had already resulted in zones of weakness if not of faulting prior to mineralization.

The ores at the Waldo Copper mine and the Fall Creek prospect are closely associated with greenstone-serpentine contacts but in each case the ore is in serpentine. It is not known whether these are fault or intrusive contacts. Some post-ore movement has occurred at both of these mines as the ores are slickensided. The ore replaces the country rock parallel to the schistosity at the Silver Peak mines and the Oak mine. A fault parallels the mineralized zone at the Oak mine and is probably pre-ore. Pre-mineralization faulting has not been reported at the Silver Peak mines; however, post-mineral faults parallel and cut the ore zone.

The Orebodies. The copper ore is in tabular and irregular lens-shaped bodies which range from very small to large masses. The orebodies in serpentine (Waldo Copper mine and Fall Creek prospect) are generally small to moderate discontinuous lenticular bodies. The original size and continuity may have been considerably altered by faulting as Winchell¹³ indicated has happened at the Waldo Copper mine. The ore, in greenstones and schists, occurs in shoots parallel to the schistosity.

Nearly all of the orebodies show more or less gradational contacts. These are most prominent in the schist and greenstone deposits of the Silver Peak, Oak and Mammoth Lode properties. In ore enclosed by serpentine, the contacts are quite sharp, especially where post-ore movements have taken place, although polished specimens show textures indicating replacement of ser-

¹³ Winchell, A. N.: Petrology and mineral resources of Jackson and Josephine counties, Oregon. Mineral Resources of Oregon, 1: 253, 1914.

pentine minerals by sulphides as well as sulphide veinlets cutting the serpentine.

Gold Deposits.

Distribution. There are numerous gold mines and prospects scattered throughout southwestern Oregon in the area extending from the Pacific Coast to the Cascade Range on the east. The sites of the largest and most successful mines are located in the Grants Pass area.

Relation to Country Rocks. Gold-bearing quartz veins are widely distributed in this area and are found in all of the pre-upper Cretaceous rocks. Greenstones are chiefly mentioned as the host rocks in much of the literature dealing with the mines. Some productive veins are associated with metamorphosed sediments, quartz-diorite, and granodiorite, and some are found in peridotites and related serpentines. A few widely scattered veins are located in the belt of Tertiary (Miocene) lavas overlying the eastern part of the area.

Associated Intrusive Rocks. Mineralized zones in the Tertiary lavas are closely associated with igneous rocks ranging from dioritic to granitic.¹⁴ In the Bohemia district several of the mines are exploiting veins within the intrusive rocks. In the older rocks, many of the gold-quartz veins occur in an area where several small and a few large bodies of quartz-diorite and related rocks crop out at the surface. These igneous rocks are thought to be surface exposures of a large batholith underlying the region. Some mines and prospects are located on veins that are several miles from surface exposures of acid igneous rocks. Two mines, the old Granite Hill and the Ashland, are located within quartz-diorite and granodiorite respectively.

Structural Relations. Veins occur most frequently in faults or faulted zones which are found cutting all of the older rocks of the region and may or may not parallel the schistosity of metamorphic rocks. Some are located in or near contacts of intrusive and sedimentary rocks; some cut both metavolcanic

¹⁴ Callaghan and Buddington: op. cit., p. 22.

rocks and metasediments or parallel their contacts; other veins in greenstone are reported to die out or to be cut off at serpentine contacts with the greenstone.¹⁵

In general the gold-quartz veins may have diverse orientations but in the Grants Pass Quadrangle Wells¹⁶ finds that the majority strike either N. 60° W. or N. 30° E.; the dips range from vertical to 40° and they slope both to the northeast and southwest and to the northwest and southeast.

The Orebodies. The gold-bearing quartz occurs in veinlets, veins, and brecciated zones. The veins are not persistent for any distance and within their known extent pinch and swell. These irregularities result in lens-shaped and tabular bodies of quartz with greatest dimensions parallel to the fissure or fault zone. Each vein may contain one or several lenses ranging from a few feet to a few hundred feet in length and averaging three to four feet wide. Locally widths are much greater. A few veins occupy strong persistent fracture zones where they may have an en echelon arrangement. Only rarely is ore developed in rock adjacent to the veins.

Within the quartz veins, commercial ore is usually confined to shoots whose limits are determined by the grade of ore that can be profitably worked. The "shoots" are related to structural or textural features. Intersections of fractures, shears, or faults may result in development of higher-grade ore. At the Sylvanite mine¹⁷ this type of structural control is reported to have resulted in the development of an ore shoot which was continuous down a fault intersection for 600 feet and discontinuous for another 200 feet. Ore shoots may develop along permeable zones in veins during the final stages of mineralization. This type may be much more irregular in regard to high-grade ore.

Sharp contacts are characteristic of the gold-quartz veins and the country rock. Some brecciated or sheared zones may show

¹⁵ Diller, J. S.: Mineral resources of southwestern Oregon. U. S. Geol. Surv. Bull. 546, 1914.

¹⁶ Wells: op. cit. (Grants Pass Quadrangle).

¹⁷ Unpublished material from the office files of the State Assay Laboratory, Grants Pass, Oregon.

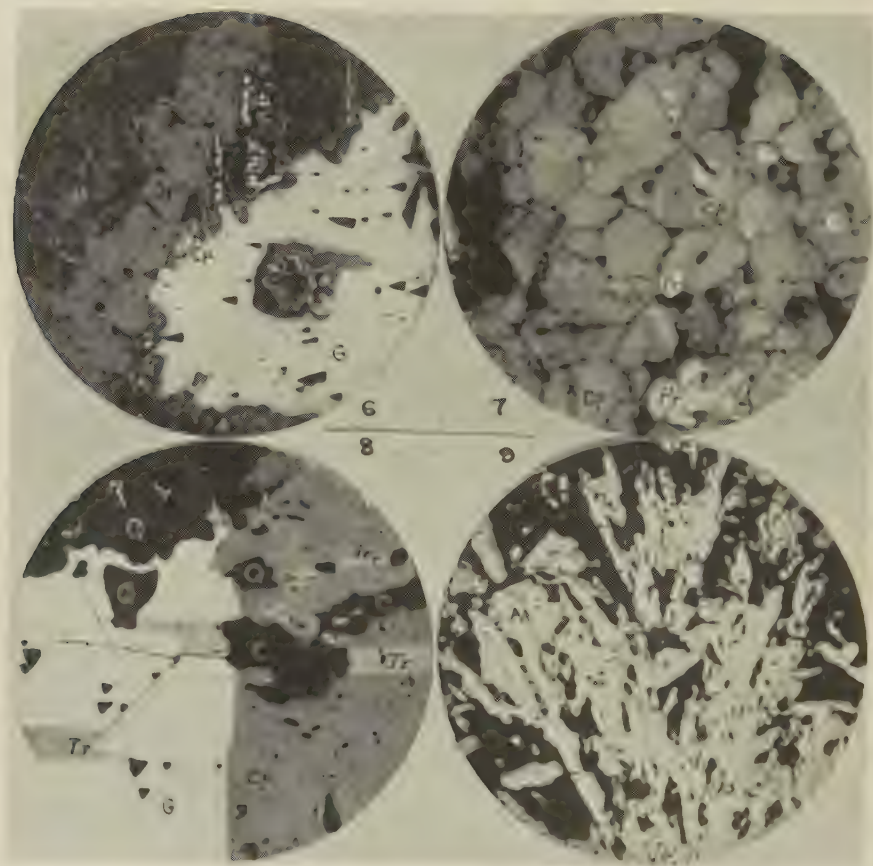


FIG. 6. Specularite (S) developed along sphalerite (Sph)-galena (G) contact. Chalcopyrite (Cp). (Musick mine, Bohemia district.) Magnification 48 $\times$.

FIG. 7. Chalcopyrite (Cp) and an unidentified mineral (X) in relations similar to those exhibited by chalcopyrite and cubanite. (Fall Creek Copper mine.) Magnification 48 $\times$.

FIG. 8. Tetrahedrite (Tr) veinlets cutting chalcopyrite (Cp) and galena (G). Quartz (Q); cavities (c). (Helena mine, Bohemia district.) Magnification 48 $\times$.

FIG. 9. Arsenopyrite (As) in frond-like growth. Gold (Au) blebs parallel the fronds. (Warner prospect.) Magnification 48 $\times$.

more or less gradational zones due to the amount of country rock enclosed in the veins. Gradational contacts are developed in at least two mines (Almeda and Anaconda) where the ore occurs in contacts between igneous rocks and slates. The ore has developed in the porphyritic-dacite (Almeda) and greenstone (Anaconda) by replacement, while the ore and slate contacts are comparatively sharp at both mines.

Mineralogy.

For the most part the gold ores of the area are similar in mineralogy. The sulphide minerals vary from mine to mine and one or more of the various minerals may be dominant so that an ore may be described as a pyrrhotite or an arsenopyrite-bearing ore. At the Peck and Anaconda mines, the ore is dominantly arsenopyrite and quartz. The Humdinger ore contains considerable pyrrhotite and some telluride. Tetradymite, native bismuth and cassiterite occur at the Irwin prospect; and tetradymite, native tellurium, and altaite occur at the Jewett mine. The ores are essentially pyrite and quartz, but generally sphalerite, chalcopyrite and galena are present in varying proportions with other sulphides or tellurides in minor amounts.

The copper deposits can be classified into two types of ore on the basis of the mineralogy. The first includes the Waldo and Fall Creek ores which are high in pyrrhotite with varying amounts of pyrite and chalcopyrite. The Fall Creek ore contains some pentlandite, while some arsenopyrite, sphalerite, and rarely native gold are present in the Waldo ore. In the second type, represented by the Silver Peak and Oak mines, pyrrhotite was not observed and sphalerite becomes nearly as abundant as chalcopyrite.

Chalcopyrite is the important primary copper mineral in both types of deposits. Tetrahedrite, tennantite and primary bornite are intergrown with chalcopyrite in the Silver Peak ores. Secondary copper sulphides, oxides and carbonates are not abundant.

The metallic minerals have been identified by various etch

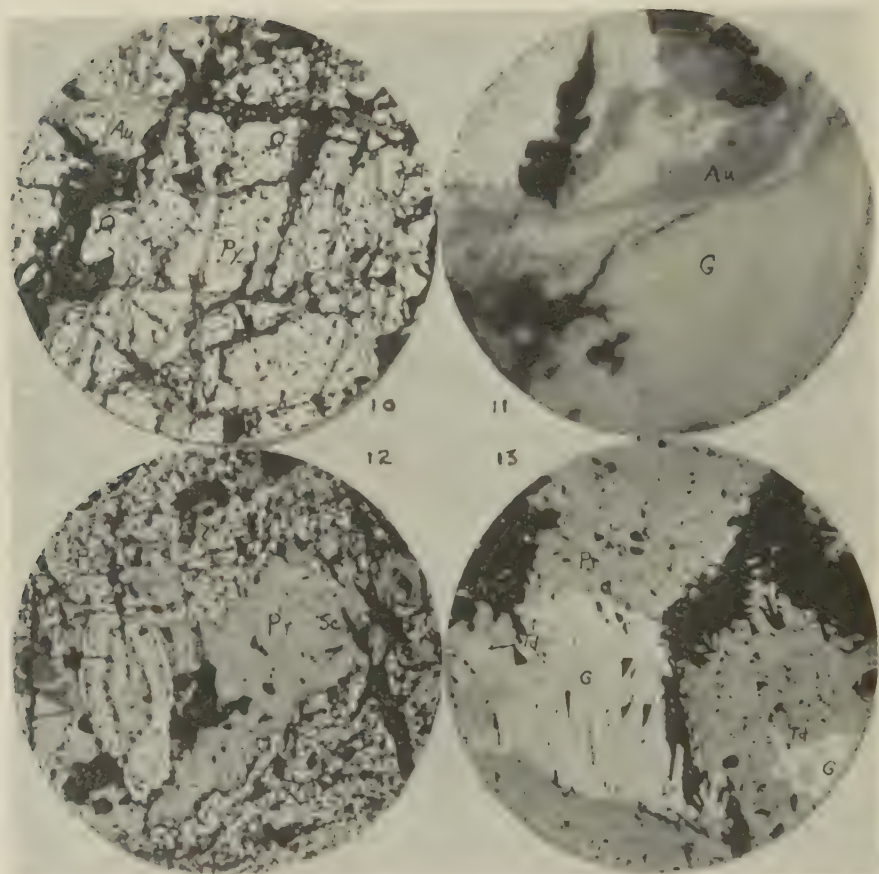


FIG. 10. Gold (Au)-quartz (Q) segmented veinlets in pyrite (Py). (Ashland mine.) Magnification 48 $\times$.

FIG. 11. "Steel" galena (G) and gold (Au) streamers. Galena reacted to deformation by granulation and recrystallization, and gold flowed. (Granite Hill mine.) Magnification 200 $\times$.

FIG. 12. Pyrite (Py) replacement of pyrrhotite (Pr); pyrite is definitely related to and later than sericite (Sc) veinlets. The ellipsoidal form may be marcasite although it grades into pyrite. (Humdinger mine.) Magnification 48 $\times$.

FIG. 13. Sericite veinlet cuts pyrrhotite (Pr) and galena (G). Tetradymite (Td) grains and rodlets along galena cleavage and boundary. (Humdinger mine.) Magnification 48 $\times$.

tests.¹⁸ If etch tests and optical properties were not decisive, microchemical tests were made to determine the elements present.¹⁹

Hypogene Minerals. A small group of minerals—pyrite, quartz, sphalerite, chalcopyrite, galena and calcite—are present in varying amounts in practically all of the ores. The other minerals were identified in a few or only in one or two mines. Only the most interesting features of the mineralogy will be discussed.

Free gold was observed in many of the ores. In some ores it was in grains sufficiently large to see with the unaided eye, but generally it was very fine-grained and intimately intergrown with pyrite, arsenopyrite, quartz, galena, and chalcopyrite (Figs. 9, 10). An intimate and somewhat unusual intergrowth of gold, tetradymite, native tellurium, and altaite occurs in the Jewett and Carter ore (Fig. 14). An interesting reaction to deformation was revealed in gold ore from the Granite Hill mine. Pyrite shattered to tiny grains; chalcopyrite fractured on a much larger scale; galena, in part, fractured along cleavage lines and, in part, recrystallized to fine-grained steel-galena. Gold inclusions in galena were deformed by flowage to develop long wavy streamers (Fig. 11) as the galena reacted by granulation and recrystallization. The characteristic triangular pits of galena are absent in the area of gold streamers but are numerous in adjacent fractured areas.

Silver is present in small amounts in several ores but hessite was the only mineral identified. Some gold, at the Ashland mine, varies from a pale yellow to a deep yellow color and is probably silver-bearing. Tetrahedrite may be silver-bearing in some ores, although silver tests were negative.

Chalcopyrite is the dominant copper mineral with minor amounts of tetrahedrite and primary bornite. Chalcopyrite and bornite are frequently observed as intergrown areas of cross-hatch appearance (Fig. 5) in the Silver Peak ore. Bornite is al-

¹⁸ Short, M. N.: Microscopic determination of the ore minerals. U. S. Geol. Surv. Bull. 914, 1940.

¹⁹ Short: op. cit.; Chamot, E. M., and Mason, C. W.: Handbook of Chemical Microscopy, 2nd edit. Vol. II. John Wiley, New York, 1940.

ways the matrix and chalcopryrite forms the bars which narrow at intersections. Contacts of bars with matrix are sharp. Nearby bornite-chalcopryrite contacts are also sharp and fail to show replacement phenomena.

Similar intergrowths have been reported as resulting from replacement of bornite by chalcopryrite, and by separation from a solid solution of bornite-chalcopryrite.²⁰ Schwartz believes that

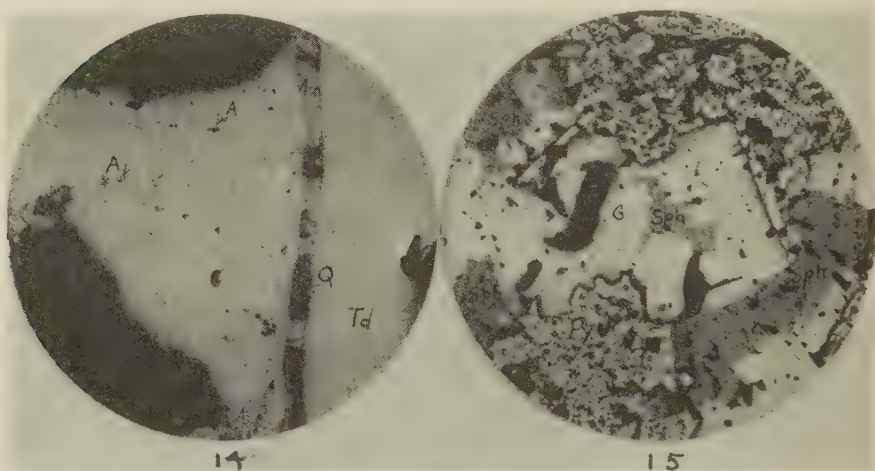


FIG. 14. Gold-quartz segmented veinlet cuts tetradymite (Td). Altaite (A) inclusions in tetradymite. (Jewett mine.) Magnification 48 X.

FIG. 15. Sphalerite (Sph) and pyrite (Py) conform to galena (G). (Al Sarena mine.) Magnification 48 X.

if the bars narrow at intersections they are most likely to be exsolution products, but if the intersections widen then replacement is indicated. He concludes that in the case of exsolution such intergrowths are formed at or above 475° C.

The chalcopryrite-bornite intergrowths of the Silver Peak ore are identical to similar intergrowths obtained artificially by Schwartz. The microphotographs show fractures cutting the intergrowths, but these are definitely later as the bars on one side

²⁰ Schwartz, G. M.: Intergrowths of bornite and chalcopryrite. *ECON. GEOL.*, 26: 200, 1931.

are continuations of those on the opposite side. Covellite is slightly developed along the fractures. The evidence favors an exsolution origin for these intergrowths.

An unidentified mineral (X), is present in the Waldo and Fall Creek copper ores. Mineral X and chalcopyrite (Fig. 7) exhibit relations similar to those of cubanite and chalcopyrite. Such a mineral is reported by Schneiderhöhn and Ramdohr to occur with chalcopyrite in ores deposited at high temperatures.²¹ They state that it is probably deposited in solid solution with chalcopyrite and "exsolution" results upon cooling. Laths of mineral X in chalcopyrite may be wide or narrow and often intersect to form V or triangle shapes. In the Fall Creek ore it may compose entire grains similar to those of Fig. 7.

Cassiterite is present at the Irwin molybdenite prospect. A spectrographic analysis shows Sn to be present in quantities between 0.1 and 1.0 per cent. Cassiterite is apparently somewhat replaced by chalcocite and covellite which makes its appearance deceiving. It occurs as small irregular and rounded grains in chalcopyrite and as cavity-fillings in pyrite.

Bismuth is also found in the molybdenite ore in quantities up to one per cent. The mineral assemblage is similar to that listed by Dana as occurring in association with cassiterite.²² Alteration has affected both bismuth and tetradyomite with development of a dark gray, nonmetallic mineral. Montanite, a secondary mineral containing Bi and Te, has been reported from Montana as encrustations on tetradyomite, and this alteration product may possibly be montanite.

²¹ Schneiderhöhn, Hans, and Ramdohr, Paul: *Lehrbuch der Erzmikroskopie*. Gebrüder Borntraeger, Berlin, 1931. Vol. II, pp. 349, 127-28. Mineral X is similar to a mineral which these writers report to be nickel-bearing; it shows no relief above chalcopyrite and is apparently of the same hardness. It is strongly anisotropic; polarization colors similar to those of pyrrhotite—gray and brown. The color in reflected light is yellowish-gray against pyrrhotite and light gray against chalcopyrite. This is probably the same mineral which Shenon describes as cubanite in the nearby Queen of Bronze and Cowboy mines in U. S. Geol. Surv. Bull. 846B, 1933.

²² Dana, E. S.: *A Textbook of Mineralogy*, 4th edit. John Wiley, New York, 1932, p. 497.

Tellurides were identified in only a few of the gold-quartz ores. They seem to be most abundant in some of the ores from the Irwin prospect, Jewett, Carter, Red Rose and Humdinger mines. Although gold was observed to be closely associated with the tellurides from most of these mines, microchemical tests of the tellurides for gold and silver were negative while bismuth and lead tests were positive. The tellurides include native tellurium, tetradymite, altaite, sylvanite (?), and hessite (?).

Intimate intergrowths of native tellurium, tetradymite and altaite (Jewett mine) are common. In these instances all three minerals may be elongated with their cleavages parallel, and tetradymite and tellurium are recognized with difficulty. Etching with FeCl_3 , however, produces an iridescent stain on tetradymite and the contacts then stand out. Altaite occurs in both of the other tellurides as rounded, irregularly rounded, lens-shaped areas, or combinations of these, within or along contacts.

Gold is intimately intergrown with tetradymite along twinning directions as microscopic grains and as elongated lens-like bodies parallel to tetradymite and tellurium cleavage.

Barite is fairly abundant at the Almeda and Silver Peak mines where in places it makes up much of the gangue. At the Helena mine, Bohemia district, barite in well developed crystals up to one-half inch long, lines vugs and fractures, and appears to be the latest mineral deposited. In the Almeda and Silver Peak ore, barite replaces quartz and fills fractures in pyrite, chalcopyrite, and tetrahedrite. The copper sulphides fill cavities in barite that are similar to cavity-fillings in quartz. Barite was deposited late in the mineralizing stage and was followed by sericite which is developed as shreds in fractures in barite. Some overlap with the copper sulphides and galena is indicated by unfractured areas where the sulphides appear to be cavity-fillings in barite and have sharp contacts with it.

Arsenopyrite is abundant in the Peck, Anaconda and Warner ores, and is present in minor amounts in a few others. It occurs as diamond-shaped sections, broken fragments and irregular masses.

Arsenopyrite from the Warner prospect is in spreading, fern-like forms of irregular rods, rectangular to parallelogram-shaped plates, and skeleton crystals (Fig. 9). Lines of tiny gold blebs parallel the fronds, and gold fills the cavities in the skeleton crystals. Some of these are several millimeters from the base to the ends of the fronds. The way gold blebs parallel the branches indicates the possibility of more or less continuity of spaces which permitted the gold-bearing solutions to circulate within and through the skeleton arsenopyrite crystals.

Late arsenopyrite is developed in sphalerite (Al Sarena mine), where it is related to fractures, and develops euhedral forms by automorphic replacement of sphalerite. The absence of similar veinlets in later sulphides indicates that this late arsenopyrite was deposited before chalcopyrite and galena.

Some pyrite, in the Bohemia and Barron ores, occurs as spherules in chalcopyrite. Spherules may be hollow or solid, and partially or completely filled by tetrahedrite, bornite and chalcopyrite. Similar occurrences of pyrite have been interpreted as resulting from deposition of pyrite as a gel followed by later dehydration and crystallization.²³ The absence of pyrite spherules in quartz, sphalerite, and galena, but their presence adjacent to these minerals suggests deposition in cavities between them. Later, chalcopyrite filled in the remaining space and partially replaced some areas. Numerous tiny pyrite blebs scattered through the chalcopyrite matrix appear to be replacement remnants. On the other hand, the presence of marcasite, as veinlets cutting sphalerite and galena, and rimming chalcopyrite, and as irregular anisotropic grains in spherulitic areas, suggests a close relationship between marcasite and pyrite spherules, but the spherules are not all anisotropic. Evidence places marcasite as one of the latest minerals, nearly as late as calcite, and although some pyrite seems to be intermixed, the chalcopyrite and tetrahedrite fillings of some cavities indicates that the spherulitic pyrite is earlier than these minerals.

²³ Schneiderhöhn and Ramdohr, *op. cit.*, pp. 166-67.

In the Bohemia district the age relation of marcasite to specularite is not clear. Alteration products of pyrrhotite in the form of round grains (Fig. 4) in the Fall Creek ore, and ellipsoidal forms with concentric texture (Fig. 12) in the Humdinger ore, are similar to marcasite and pyrite textures described by Schneiderhöhn and Ramdohr and by C. P. Ross respectively. This mineral is intergrown with pyrite, and it may indeed be pyrite as it is not anisotropic and does not react to staining solutions. The absence of associated supergene sulphides in adjacent chalcopyrite suggests a hypogene origin.

Specular hematite is commonly observed in ores from the central part of the Bohemia area. In hand specimen it appears as deep red streaks following chalcopyrite-quartz contacts, and fractures, as alternating bands with quartz in ribbon veins, and as disseminated needles in quartz crystals. Under the microscope it forms slender needles and very rarely plates.

Hematite is later than sphalerite, chalcopyrite, and galena and earlier than carbonates. It automorphically replaces quartz, sphalerite, chalcopyrite and galena along contacts of these minerals (Fig. 6), and in one specimen was observed to cut sphalerite and an enclosed chalcopyrite veinlet.

Minor amounts of ilmenite are intergrown with specular hematite in the Bohemia ores.

Supergene Minerals. Secondary sulphides are not abundant and in many ores are absent. Oxidation and erosion appear to be about equally paced, therefore the oxidation zones rarely exceed a hundred feet in depth, and usually are much less. Limonite is the characteristic oxidation product. Gold values are reported somewhat higher than in unoxidized ore. The products of leaching are apparently carried away in the groundwater circulation as secondarily enriched ore, if present at all, is restricted to a narrow zone.

In the Bohemia veins chalcocite, bornite and covellite are developed as aureoles around adjacent minerals; bornite selectively replaces chalcopyrite, chalcocite replaces galena, and covellite replaces sphalerite. Cuprite was definitely identified only in the

Mammoth Lode ore where it selectively replaced chalcopyrite whereas adjacent sphalerite was replaced by covellite. In this instance no secondary copper sulphide appears to precede the cuprite as would be expected.

PARAGENESIS OF THE ORE MINERALS.

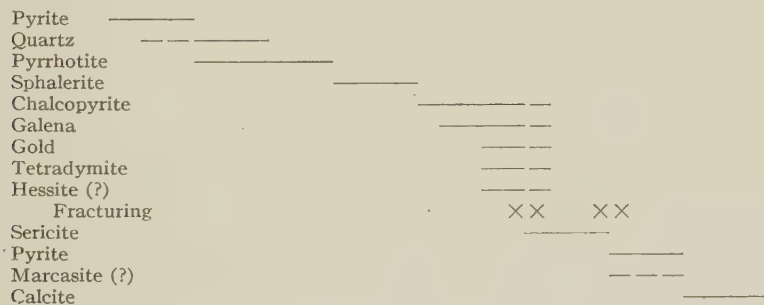
Paragenesis of the Gold Veins.

Pyrrhotite-gold-quartz Veins. The Humdinger and Frog Pond mines (Fig. 1) are located on veins of the pyrrhotite-gold-quartz type. The Humdinger ore is dominantly quartz with abundant pyrrhotite and pyrite and minor amounts of sphalerite, chalcopyrite and galena. Gold is present as native gold. The tellurides gave negative tests for gold, and a doubtful test for silver from a mineral identified by etch tests as hessite. In specimens studied from the Frog Pond mine, pyrrhotite was more abundant in wall-rock specimens adjacent to the vein and pyrite more abundant in the vein material. Other sulphides are sparse and minor differences exist in the sequence for each mine but the general features are similar.

The mineralization was apparently continuous, with the same order of deposition at each mine. The early sequence was pyrite, quartz and pyrrhotite with possible overlap of pyrite and quartz, and overlap of quartz and pyrrhotite.

A composite paragenesis sequence for the Humdinger and Frog Pond ores is shown below:

Hypogene Minerals:



Pyrite cubes and fragments contain quartz and pyrrhotite veinlets. Angular pyrite fragments are so enclosed by quartz to indicate cavity-fillings, while quartz and pyrrhotite exhibit reversible relationships, and re-entrants of each in the other are common. Sphalerite was deposited next in the sequence. It occurs as cavity-fillings in quartz and pyrrhotite and is automorphic against chalcopyrite and galena.

Deposition of chalcopyrite and galena followed sphalerite. Galena displayed a tendency to wrap around some chalcopyrite indicating chalcopyrite in part was earlier. Late in this stage, gold, tetradymite, and hessite were deposited in the Humdinger ore. They frequently developed as irregular but rounded grains within chalcopyrite and galena or along chalcopyrite and galena contacts with pyrrhotite, and as cavity-fillings and in veinlets in all three sulphides and in quartz, and are contemporaneous with late chalcopyrite and galena.

Fracturing interrupted or ended this mineralizing epoch in both ores. At the Frog Pond mine, fracturing was followed by introduction of pyrite as veinlets in the older minerals. Sericite developed and filled fractures in the Humdinger ore (Fig. 13). Some chalcopyrite, galena, gold and tellurides are possibly later than some sericite as they fill triangular spaces between sericite plates although these triangular areas may be the result of automorphic replacement by sericite. Pyrite was introduced along both walls and within sericite veinlets in the form of parallel veinlets conforming to sericite plates on the one side and developing irregular contacts with pyrrhotite on the other. Extensive replacement of pyrrhotite by pyrite seems to have taken place in some areas. Reopening of sericite-filled fractures and opening of new ones apparently preceded the pyrite as pyrite veinlets also cut pyrrhotite, quartz, and the earlier sericite veinlets. Calcite-bearing solutions partially replaced sericite and pyrite veinlets along the central sericite band in the Humdinger ore, and developed veinlets in the Frog Pond ore.

Pyrrhotite, diagnostic of high temperature and pressure, is present in the early mineralization stage at each mine. The tel-

lurides, tetradymite and hessite deposited later occur in a wide range of temperature and pressure conditions. Diopside and adularia are diagnostic gangue minerals in the Humdinger ore; black tourmaline is reported in the Frog Pond ore. Diopside was observed as tiny grains enclosed by quartz, similar to that of the argillite wall rock, and separated from pyrrhotite masses by quartz. It seems to be developed along the vein wall-rock contact. Both diopside and tourmaline are diagnostic of high temperature-pressure conditions. Adularia appears as veinlets within the quartz vein and is a late mineral in, if not later than, the veins. Adularia is characteristic of the epithermal zone.²⁴

The high temperature minerals—pyrrhotite, diopside, and black tourmaline indicate that the orebodies were deposited in the hypothermal zone.

Arsenopyrite-gold Veins. The arsenopyrite-gold veins have similar mineralogy to the other vein types but are characterized by abundance of arsenopyrite. Arsenopyrite-bearing ore is found at the Peck and Anaconda mines and the Warner prospect (Fig. 1), and consists mainly of quartz with arsenopyrite, although pyrite, sphalerite, chalcopyrite, and gold in minor amounts may be present. Gold is most abundantly associated with arsenopyrite but does occur in pyrite and quartz.

The general sequence of mineralization, as shown in the following composite paragenesis diagram, is typical for each of the mines in which variations are due to the absence of one or more minerals. For instance, in the Peck ore pyrite, chalcopyrite, and sphalerite were not observed.

Hypogene Minerals (Peck, Anaconda and Warner mines):



²⁴ Ore Deposits of the Western States. A. I. M. E., New York, 1933, p. 36.

Pyrite, arsenopyrite and then quartz, with some overlap, were the first minerals to be deposited. Pyrite, as cubes, is automorphic against arsenopyrite and quartz, with rarely a diamond-shaped section of arsenopyrite enclosed in a pyrite cube. Arsenopyrite is commonly automorphic against quartz, although many sections are only partially developed. Quartz veinlets, continuous with quartz matrix, cut pyrite and arsenopyrite. Evidence for quartz overlap with pyrite is not decisive.

Sphalerite and chalcopyrite were apparently deposited next and occur as cavity-fillings in quartz or between arsenopyrite-quartz contacts. Chalcopyrite cavity-fillings occasionally occur in arsenopyrite. Sphalerite and chalcopyrite were not observed together, but since they exhibit similar relations to the other minerals they appear to be contemporaneous.

Galena wraps around both sphalerite and chalcopyrite and is evidently younger. Gold fills cavities in arsenopyrite and as rounded to automorphic grains is enclosed by galena. Tiny gold veinlets cut arsenopyrite and galena. Gold and galena are contemporaneous with gold deposition continuing slightly beyond galena.

Fracturing followed galena and gold deposition with quartz introduced into the fractures. Some quartz veinlets in galena are continuous with quartz matrix and may indicate that quartz deposition was continuous from the early to the late mineralization period. Quartz deposition may have given way to calcite-bearing solutions.

Mineralization was continuous with the early minerals overlapping in the early stage. The intermediate stage, represented by sphalerite, chalcopyrite, galena and gold, was apparently ended by a period of minor adjustments within the veins. In the late stage quartz and calcite veinlets cut the sulphides and quartz gangue.

The ore minerals present are "persistent," and are found in deposits ranging from high to low temperature-pressure environments. However, arsenopyrite is more characteristic of the intermediate zone than of the shallow zone. These ores are considered to be mesothermal deposits because of abundance of

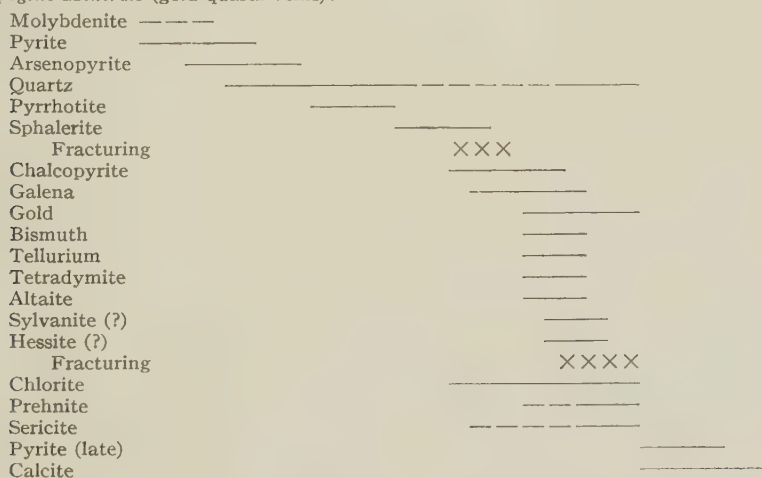
arsenopyrite and lack of diagnostic minerals of either the hypothermal or epithermal zones.

Gold-quartz Veins. The quartz-gold veins are pyrite and quartz with minor amounts of various sulphides, gold, tellurides and gangue minerals. The mineralogy of some veins is relatively simple consisting of quartz, pyrite, chalcopyrite, gold and calcite. Other veins contain a large number of minerals, but the paragenesis sequence follows a similar pattern for nearly all of the veins.

Mineralization of two widely separated periods is represented in these veins. The older veins, emplaced in pre-upper Cretaceous rocks are thought to be genetically related to post-Jurassic or early Cretaceous intrusives. The younger veins occur in Tertiary lavas and are believed to be genetically related to intrusives of late Miocene age. For comparative purposes a paragenesis diagram is given for each of these periods of mineralization. The late-Miocene (?) mineralization undoubtedly represents deposition at considerably less depth than the older period.

Polished sections from the older gold-quartz veins reveal two periods of fracturing which divide the mineralization into three stages. Early fracturing occurred near the completion of sphalerite deposition and the later fracturing followed near the end of galena deposition.

Hypogene Minerals (gold-quartz veins):



In the early stage pyrite, arsenopyrite and quartz were deposited in succession with overlap. All three minerals are in places automorphic against each other. Pyrite is dominantly automorphic, with arsenopyrite usually conforming to pyrite but dominantly automorphic against quartz. Quartz is occasionally automorphic against the others but may fill fractures in them. In some deposits quartz crystallization apparently ceased before pyrrhotite and sphalerite were deposited, although in others it continued into or possibly through the intermediate and into the third stage. Often there is no evidence of continual deposition, but quartz veinlets in galena cleavage fractures indicate a second generation of quartz crystallizing in the late stage.

Wherever pyrrhotite and arsenopyrite were associated, pyrrhotite veinlets in euhedral arsenopyrite furnish definite evidence that the pyrrhotite is younger.

Sphalerite deposition, if present, was followed by fracturing in nearly all the ores. Thus sphalerite appears to belong to the early stage. It was not observed as fracture-filling in pyrrhotite, but is enclosed as cavity-fillings by pyrrhotite or conforms to its outlines. Chalcopyrite, as dots and rods along sphalerite cleavage, is the only occurrence of chalcopyrite in the early stage and is probably due to exsolution.

The intermediate stage is characterized by a number of minerals that were deposited simultaneously or with overlap.

Chalcopyrite and galena, generally earlier than gold, conform to the outlines of earlier minerals or cut them as veinlets. Chalcopyrite-galena segmented veinlets cut sphalerite, pyrite and quartz; galena-quartz-gold veinlets cut pyrite.

Gold is rarely enclosed as dots and grains near the outer edge of chalcopyrite grains, and frequently as larger rounded grains it is enclosed by galena. Gold veinlets transecting galena-chalcopyrite boundaries are common. Gold and tellurides exhibit reversible relationships and are generally contemporaneous, but the frequency of gold veinlets cutting all of these minerals indicates that it continued to deposit after the late period of fracturing. Sylvanite and hessite are associated with gold in chalcopyrite at

the Chieftain and Continental mines. The tellurides display the same relationships to the older minerals as does gold.

Chlorite, sericite and prehnite have nearly identical relations and all appear to be developed in both the intermediate and late stages, although all three are best developed along fractures that were formed at or near the end of the intermediate stage.

A second generation of pyrite occurs as veinlets in many of the ores. It is later than some calcite as it follows calcite cleavage directions and may or may not be followed by later calcite.

Direct evidence bearing on the temperature-pressure environment in which these veins were deposited is scant. The veins are characterized by persistent minerals. Pyrrhotite is present in some veins as widely disseminated grains. Bismuth, present in the Irwin ore, is probably the only other diagnostic mineral. It is formed at temperatures not exceeding its melting point of 271° C.²⁵

However, some information is available in the association of mineralized areas adjacent to or within granodiorite and quartz-diorite bodies. The quartz veins appear to be genetically related to the post-Jurassic intrusive rocks of the region. Intrusive rocks are present in the vicinity of many of the veins while the Ashland and Granite Hill orebodies are developed within intrusives.

If these intrusives and quartz veins were derived from the same parent magma, there was probably no extended hiatus between the deposition of the Ashland and Granite Hill orebodies and the solidification of their respective host rocks. In these cases, mineralization undoubtedly took place at a considerable distance below the surface. Likewise those veins in the vicinity of quartz-diorite or granodiorite intrusives, were probably deposited at considerable depths. This assumption is borne out by the present topography. There is a difference in elevation of approximately 6,000 feet between the lowest and highest points on exposed quartz-diorite bodies which are thought to be part of one large

²⁵ Bowen, N. L.: *Geologic Thermometry. The Laboratory Investigation of Ores.* McGraw-Hill, New York, 1928, p. 179.

batholith underlying the region.²⁸ Therefore, erosion has removed at least 6,000 feet of overlying rock from some parts of the batholith without considering the thickness of the rocks into which the quartz-diorite was intruded.

Because of the lack of diagnostic minerals of either the hypothermal or epithermal zones and because topographical evidence points towards mineralization at considerable depth, most of the gold-quartz veins are considered to be mesothermal deposits.

The Tertiary gold-quartz veins are represented by the Bohemia area and by the Al Sarena and Barron mines (Fig. 1).

The following paragenesis diagram is similar to the one for the older gold-quartz veins, although several variations are readily seen. Several minerals, particularly the tellurides, are missing and new minerals have appeared.

Hypogene Minerals (Bohemia gold ores):

Quartz	—————	
Pyrite	— — — — —	
Sphalerite	—————	
Arsenopyrite	———	
Galena	—————	
Gold	— — — — —	
Fracturing		× × × × × × ×
Chalcopyrite	—————	
Tetrahedrite	—————	
Tennantite	—————	
Bornite	—————	
Specular hematite		—————
Ilmenite		—————
Dolomite		—————
Marcasite		— — — — —
Pyrite		— — — — —
Calcite		—————
Barite		—————

Supergene Minerals:

Chalcocite	—————
Covellite	—————
Bornite	—————
Anglesite	—————

An important variation is the late appearance of the high temperature minerals, specularite and ilmenite, which are present in the Bohemia veins but not in the Al Sarena or Barron veins.

²⁸ Wells: op. cit. (Grants Pass Quadrangle).

There are several other differences. Sphalerite and pyrite overlap. Sphalerite, galena and the copper-bearing minerals were deposited in an overlapping sequence in which sphalerite deposition began slightly earlier than galena, and galena deposition began slightly earlier than chalcopyrite. All three are in places automorphic against each other (Fig. 15). Galena, chalcopyrite, and tetrahedrite veinlets are common in sphalerite; chalcopyrite veinlets frequently cut galena; and tetrahedrite veinlets cut galena and chalcopyrite (Fig. 8). A tiny stringer of euhedral arsenopyrite is developed along a fracture in sphalerite but was not observed in other minerals.

Quartz deposition was continuous through the early and intermediate stages. It is automorphic against all the minerals and also conforms to most of the sulphides. Quartz and chalcopyrite crystals are perfectly developed in vugs where either may overlie the other.

In the early and intermediate stages mineralization seems to have been continuous, with the minerals overlapping. Before completion of galena and chalcopyrite deposition, fracturing occurred and the fractures were filled by these minerals and tetrahedrite.

The late stage in the Bohemia ore is characterized by introduction of specularite and ilmenite along contacts of earlier minerals, along contacts of "bands" in some banded and comb veins, and along fractures.

Specularite automorphically replaces all of the minerals except pyrite. It is best developed in quartz matrix and euhedral quartz, but needles transect sulphide boundaries (Fig. 6), cut sphalerite grains and intersect a chalcopyrite veinlet in sphalerite. Age relations of marcasite-pyrite veinlets to specularite are not decisive, although specularite appears to be later.

Carbonate deposition followed specularite. Fine-grained dolomite replaces quartz in some areas and cuts veinlets containing specularite. Rosettes of curving dolomite crystals are developed on quartz and chalcopyrite crystals in vugs. Calcite veinlets cut dolomite and lead to calcite crystals lining vugs.

The final stage was apparently completed by barite deposition. Barite crystals are developed in vugs and fractures but barite was not identified as forming part of the matrix. Its age relations to calcite are not certain as these two were not found in association although both line vugs and openings.

At the Al Sarena and Barron mines, the mineralization sequence is similar with the exception that deposition was completed in two stages. Carbonates were not identified in these ores.

Nearly all of the metallics in these veins are persistent minerals without diagnostic value. Tetrahedrite, marcassite and barite are characteristic of mesothermal and epithermal deposits while specular hematite is diagnostic of high temperatures. Tourmaline, epidote, johannsenite (pyroxene?) and adularia are reported to occur in the Bohemia district. Specularite, tourmaline, and johannsenite are high temperature minerals and are assigned to an initial high temperature stage by Callaghan and Buddington.²⁷ Adularia is reported to be characteristic of epithermal deposits.²⁸

The mineralogy furnishes conflicting evidence for determining the temperature at which the veins were deposited, especially since the age relations of tourmaline, johannsenite and adularia to each other and to the other minerals are not known. Possibly the tourmaline and johannsenite are more closely related to the contact metamorphic zone than to the veins.

The writer believes that specularite is a late mineral in the Bohemia ores and that it indicates a high temperature period near the close of the mineralization period. Tourmaline and johannsenite may be related to this late high-temperature stage rather than to an initial high-temperature stage during vein formation. High temperature minerals have not been identified in the Al Sarena and Barron ores.

There seems to be a genetic relationship between the veins and small bodies of intrusive rocks that invade the Tertiary lavas.²⁹

²⁷ Callaghan and Buddington: *op. cit.*, pp. 23-28.

²⁸ *Ore Deposits of the Western States*, p. 36.

²⁹ Callaghan and Buddington: *op. cit.*, p. 22.

The dioritic intrusives invaded lavas that have a maximum thickness of 6,500 feet in the Bohemia district.³⁰ Here the Champion and Helena veins (Bohemia district) cut the intrusives. Thus the evidence points to mineralization at moderate to shallow depths. The association of tourmaline, epidote and specularite led Buddington to classify at least part of the Bohemia veins as xerithermal.³¹

The writer believes that these veins are of the epithermal type, and that the late high-temperature stage in the Bohemia veins was due to late fracturing which permitted the influx of hot solutions from another portion of the intrusive body.

Paragenesis of the Pyrrhotite-Chalcopyrite Deposits.

The mineral sequence of the Waldo Copper ore is shown below. It is similar to that of the Fall Creek ore in that the dominant minerals—pyrite, pyrrhotite and chalcopyrite—have similar relations, while the arsenopyrite of the Waldo ore and the pentlandite of the Fall Creek ore occupy similar places in the mineral sequence. Sphalerite, gold and several nonmetallic minerals are present in the Waldo ore and not in the Fall Creek ore. The age relations criteria are similar to those already discussed for the gold ores.

Hypogene Minerals:

Pyrite	_____			
Arsenopyrite	-----			
Quartz	-----			
Pyroxene (hedenbergite?)	_____			
Talc		_____		
Pyrrhotite			_____	
Sphalerite			_____	
Chalcopyrite			_____	
Mineral X			_____	
Gold			_____	
Quartz (late)				_____
Calcite		_____		
Marcasite (relations uncertain)				

Supergene Minerals:

Chalcocite			_____	
Malachite			_____	
Limonite			_____	

³⁰ Ibid., p. 40.

³¹ Buddington, A. F.: High-temperature mineral associations at shallow to moderate depths. ECON. GEOL., 30: 219-221, 1935.

The diagnostic minerals are abundant pyrrhotite and the pyroxene (hedenbergite?), both characteristically developed in high temperature and pressure environments. The ores of the Waldo Copper mine and of Fall Creek are thus assigned to the hypothermal stage.

In the Fall Creek ore, polished specimens indicate that mineralization was subsequent to serpentinization. Magnetite and chromite grains and magnetite veinlets are common with the magnetite veinlets deceptively appearing to cut all sulphide minerals as well as cutting and rimming the chromite grains. Closer inspection shows that pyrite and pyrrhotite fill fractures in magnetite and chromite grains, cut magnetite veinlets, and pyrrhotite slightly replaces portions of the magnetite veinlets. Similar magnetite veinlets are developed in chrysotile grains of the serpentine in identical relationships. Serpentinization of olivine is often accompanied by a segregation of magnetite within fractures as minute veinlets.⁸² Redistribution of the magnetite may result in still larger veinlets. Magnetite is a stable mineral under the high pressure-temperature environment involved and therefore it would be likely to persist in this deposit. These magnetite veinlets are interesting evidence that in rare instances the minerals of a vein may be *older* rather than younger than some of the minerals forming the vein walls.

Paragenesis of the Sphalerite-Chalcopyrite Deposits.

The mineral sequence of the Silver Peak ore is shown below. Ore from the Oak mine in which chalcopyrite is the only copper mineral present shows similar relationships.

Epidote, diagnostic of moderate temperatures, is the only diagnostic mineral and it was observed only in thin sections of the country rock adjacent to the mineralized zone. Evidence of higher temperature is the bornite-chalcopyrite intergrowth which, according to Schwartz, results only at high temperature (475° C.). However, the effects of time and pressure might have a

⁸² Rogers, A. F., and Kerr, P. F.: *Thin-Section Mineralogy*. McGraw-Hill, New York, 1935, p. 174.

modifying effect on the temperature range at which such an intergrowth would form.

The epidote suggests that mineralization took place in the mesothermal zone, while the chalcopyrite-bornite intergrowth places the formation of the ore in the lower limits of the mesothermal zone, if not in the upper hypothermal zone.

Hypogene Minerals:

Pyrite	----	
Quartz	-----	
Fracturing		XXX
Sphalerite	-----	
Fracturing		XX
Tetrahedrite	-----	
Tennantite	-----	
Chalcopyrite	-----	
Bornite	-----	
Galena	-----	
Fracturing		XX
Barite	-----	
Sericite	-----	

Supergene Minerals:

Chalcocite	-----
Covellite	-----
Limonite	-----

SUMMARY AND CONCLUSIONS.

Paragenetic Sequence.

A more or less arbitrary classification of the veins was undertaken to simplify the paragenetic diagrams. First, the division was made according to the principal metal recovered, secondarily, on the most abundant sulphides present in each deposit. Thus copper ores are classified as pyrrhotite-chalcopyrite, and sphalerite-chalcopyrite deposits, and gold-quartz veins are divided into pyrrhotite-bearing, arsenopyrite-bearing, and pyrite-gold-quartz veins. The latter group is again subdivided into deposits occurring within pre-upper Cretaceous rocks and within Tertiary rocks.

The individual paragenesis diagrams for the mines show many variations, but when grouped according to the above classification the composite paragenesis diagram for each type of deposit retains the general characteristics of the individual diagrams. A comparison of these paragenesis diagrams for the various types

of deposits reveals a sequence that is characteristic for the entire area.

Nearly all of the diagrams exhibit an early, intermediate and late stage of mineralization, which may or may not be separated by fracturing. Fracturing is usually not severe and appears to result from minor adjustments within the veins.

The early stage is characterized by the successive deposition, commonly with overlap, of quartz, pyrite, arsenopyrite, pyrrhotite and occasionally sphalerite. One or two of these minerals may be absent.

Chalcopyrite, various other copper sulphides and galena follow in the intermediate stage, with sphalerite belonging more or less to both the early and intermediate stages. Gold, tellurides and bismuth are contemporaneous with chalcopyrite and galena at the end of the intermediate stage.

The late stage is characterized by carbonate deposition. Often a second generation of quartz or pyrite precedes the calcite. Marcasite accompanies late pyrite in the Bohemia area and is the latest mineral in the Al Sarena ore where carbonate was not identified.

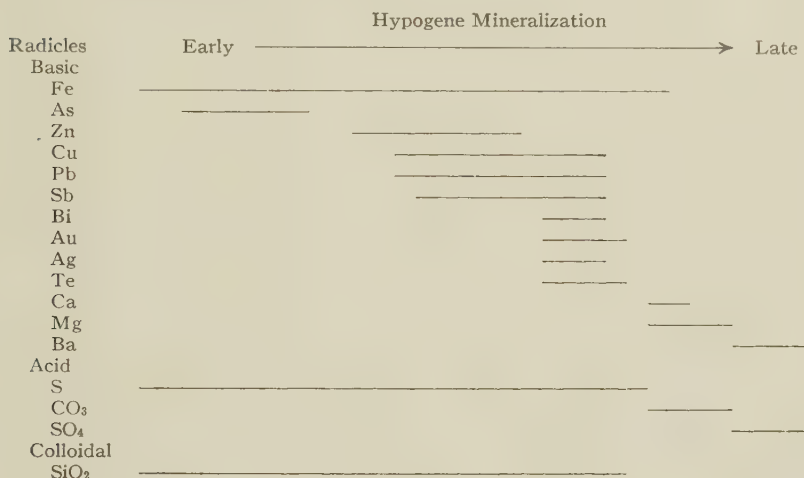
Some instances of replacement occur among the hypogene sulphides, mostly in the pyrrhotite-bearing deposits. Pyrrhotite replaces pyrite; chalcopyrite replaces pyrrhotite; and what appears to be a marcasite-pyrite intergrowth replaces pyrrhotite.

Calcite replaces arsenopyrite and chalcopyrite on a minor scale in the Jewett ore.

Although the mineralization sequence shows three stages, there is no evidence that an extended hiatus separated one stage from another. The younger minerals show late deposition by their conformity to crystal faces and outlines of the earlier minerals, by their deposition in vugs and cavities in ore already deposited, and by their occurrence in veinlets cutting the older minerals.

Although a few minerals are common in all of the ores, the presence of several others in only one or two mines produces a confusing picture if a composite paragenesis diagram is compiled for all of the mines. However, a paragenetic sequence in terms

of the radicles involved, as shown below, gives a fair interpretation of the hypogene mineralization for the region.



The deposits determined as hypothermal include the pyrrhotite-chalcopryrite deposits of the Waldo Copper and the Fall Creek mines, and the pyrrhotite-gold veins of the Humdinger and Frog Pond mines.

The mesothermal deposits include the sphalerite-chalcopryrite deposits of the Silver Peak and the Oak mines; the arsenopyrite-gold veins of the Peck, Anaconda and Warner mines; and the pyrite-gold-quartz veins which include most of the veins in the pre-upper Cretaceous rocks.

The gold-quartz veins in the Tertiary rocks are epithermal.

The order of deposition, as shown in the several paragenesis diagrams, is in accord with the sequence given by Lindgren.⁸³

Hypogene Mineralizing Solutions.

Elements and Radicles in Solutions. The ore depositing solutions, which were active over so large an area, undoubtedly differed from district to district in the variety of radicles carried.

⁸³ Lindgren, Waldemar: Mineral Deposits, 4th edit. McGraw-Hill, New York, 1935, p. 122.

The mineralogy of the various deposits reveals at least a portion of the radicles that were being transported; others may have been present in the solution but were not precipitated in the veins.

The mineralogy of the various mines shows that the following radicles or compounds were deposited in the majority of the ores: Fe, As, Zn, Cu, Pb, Sb, Au, Ca, S, CO_2 and SiO_2 . In addition, the solutions carried one or more of the radicles: Te, Bi, Ag, Mg, Ba, and SO_4 . Water was presumably the most abundant component and its presence is demonstrated by the abundance of sericite, chlorite and epidote in many ores or in the adjacent wall-rock products.

Calcite, as the latest mineral deposited in nearly all of the ores, indicates that the solutions were alkaline at least in the late stage of mineralization. Marcasite as the last mineral at the Al Sarena mine indicates that the solutions there were cool and neutral or nearly so.

Temperatures. The diagnostic metallic minerals are pyrrhotite, native tellurium, and native bismuth. Pyrrhotite is diagnostic of high temperatures; tellurium and bismuth will not be deposited at temperatures higher than their melting points of 451°C. and 271°C. respectively.

Chalcopyrite occurs as an intergrowth with bornite that is similar to exsolution textures obtained by Schwartz at temperatures of 475°C. or higher. Another chalcopyrite intergrowth with an unidentified mineral similar to chalcopyrite-cubanite exsolution textures, may have a similar temperature range of formation.

A few high-temperature nonmetallic minerals—diopside, hedenbergite (?), orthoclase, microcline and garnet—are associated with some ores.

These diagnostic minerals are present only at a few mines. However, they indicate that the ore-depositing solutions in these instances possessed moderate to high temperatures, and since the mineralogy of all the deposits is similar and of hypogene character, it is a reasonable inference that all of the mineralizing solutions were hot in the early stage.

Source of the Solutions. Many of the veins in the Grants Pass area are close to exposed quartz-diorite and granodiorite bodies. The Ashland and Granite Hill mines are located within such intrusives. In the Grants Pass area these numerous small and large intrusives are thought to be exposed portions of one large batholith which underlies the region.

The mineralized belt in the Cascade Range parallels a belt of small dioritic intrusives and in some instances the veins cut both the intrusives and the invaded lavas.

Although the source of the mineralizing solutions which deposited the copper and gold orebodies cannot definitely be related to a given body of basic or acid rock, or even to a parent magma of both rock types, the frequent association of orebodies with quartz-diorite and related rocks has led to the conclusion that the mineralizing solutions are a late segregation product from a common parent magma.

Formation of the Veins. Most of the veins are lens- or tabular-shaped bodies of varying dimensions, seldom continuous for more than a few hundred feet. A few veins appear to fill fairly simple fractures; several of them, however, occupy more or less fractured or sheared zones enclosing considerable fragmented wall-rock and more or less gouge. Within their known extent they pinch and swell both horizontally and vertically. Movement along zones of weakness or fracture would produce openings of varying size. Many of the veins furnish evidence of pre-ore shearing by the presence of wall-rock fragments enclosed by unsheared vein minerals. Veinlets with matching-walls of younger ore minerals cutting older ore minerals indicate movements during ore deposition; and slickensided ore and gangue are evidence of post-ore movements. Thus the vein structures offer evidence that the veins are emplaced in faults, or shear zones which in many cases have been unstable previous to, during, and following ore deposition.

The textures and relationships of the minerals in the early, intermediate, and late stages of the paragenesis sequence point towards deposition in cavities by aqueous solutions. The earliest

minerals—pyrite, arsenopyrite and quartz—are commonly euhedral. The later minerals either conform to euhedral outlines of earlier minerals or fill fractures in them, and also as euhedral crystals are developed normal to vug and fracture walls.

Pyrite and occasionally chalcopyrite have been introduced into the wall rocks of some veins. Sericite, chlorite, epidote and calcite are the more common wall-rock alteration products. One, two, or all may be present in individual cases as alteration or replacement products of the wall-rock minerals. The alteration zones may be narrow, fairly wide, or even missing, but more or less parallel the vein and grade into country rock away from the vein. Thus the alteration zones show a genetic relationship to the veins.

The textures, the depositional sequence of the vein minerals and the wall-rock alteration seem to be explained most simply and easily by progressive crystallization from aqueous solutions, circulating through more or less open channels, in response to gradually changing physico-chemical conditions.

Outline of Mineralization.

Magmas have invaded the rocks of southwestern Oregon at least twice since Paleozoic times. The earlier igneous rocks consisting mainly of quartz-diorite and related rock were intruded into all of the pre-upper Cretaceous rocks. This period of intrusion accompanied or followed the mountain building epoch that uplifted the Sierra Nevada Range and adjacent regions. At the present time the numerous small and a few large bodies of these igneous rocks are thought to be part of one large batholith underlying much of the Grants Pass Quadrangle and adjoining areas.

Sometime during the Miocene epoch, magma again intruded parts of the area. This intrusion is known from small bodies and dikes of igneous rocks that intrude and metamorphose Eocene sediments and Miocene lava flows along a narrow north-south trending belt in the western part of the Cascade Range.

Preceding, during, or following these intrusions the intruded rocks were subjected to fracturing or faulting. These fracture and fault systems served as channels for the aqueous solutions given off late in the crystallization of the magma.

The ore-bearing solutions moved upward and outward through fissures, fractures, shear zones and permeable rock zones to deposit ore and gangue minerals. Because the channels were more or less discontinuous the resulting quartz veins are lens-shaped-tabular bodies. The continuity of the original channels and many physico-chemical factors influenced the deposition of the ore—in places resulting in high-grade ore deposits but in other places only in lean or barren quartz.

CHICAGO, ILLINOIS,
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